



Laser Science & Technology

Dr. Lloyd A. Hackel, Program Leader

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Short-Pulse Thomson X-Ray Source

With funding from the Laboratory Directed Research and Development (LDRD) Program and in partnership with the Physics and Advanced Technologies (PAT) and the Engineering Directorates, LS&T continues to develop an ultrafast x-ray source based on Thomson scattering of fs laser pulses from relativistic electron bunches from a linear accelerator (linac). After years of intensive R&D, the experimental setups for Thomson scattering are returning results. In recent experiments, we successfully generated 70-keV x-rays with extremely high brightness. The immediate application of this intense x-ray source (40–150 keV) will be in pump-probe experiments for the Stockpile Stewardship Program to temporally resolve structural dynamics and atomic motion in high-Z materials with ps resolution.

The PLEIADES facility (which stands for **P**icosecond **L**aser **E**lectron **I**nterAction for **D**ynamic **E**valuation of **S**tructures) is located in Bldg. 194 where PAT's high-current, rf, electron linac, see Figure 1, and LS&T's fs-laser facility (Falcon) are installed. We have recently completed construction and synchronization of a dual-beam Ti-sapphire laser system for photon-electron counterpropagation experiments. A single, mode-locked oscillator is used to seed both the main IR laser system (the source of fs photons) and the photoinjector laser system (PLS, which seeds the linac). The laser master

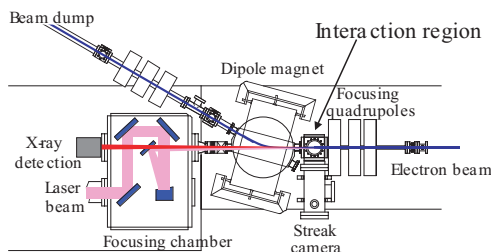


Figure 2. Layout of the Thomson interaction region: the electron bunch, indicated by the dark blue line, emerges from the linac and is focused by the quad magnet at the interaction point and deflected at an angle away from the x-ray detector by a bending magnet; the laser pulse, pink, is focused with a parabola at the interaction point and the resulting x-rays (red) travel in the direction of the electrons and are detected by the CCD camera.

oscillator is phase-locked to an rf crystal oscillator to drive the klystrons that power the linac. The PLS consists of a regenerative amplifier (regen) and single 4-pass amplifier that yields an IR output of ~100 mJ. The amplifier output pulse is compressed using a small, dual grating compressor. The compressor output pulse is frequency-tripled to 266 nm and transported to the photogun to produce photoelectrons from a polished copper cathode. The photoelectrons are accelerated to 5 MeV and injected into the linac and accelerated up to 80 MeV.

After the grating stretcher, the 600-ps pulse is amplified to 1 J by three stages: a regen, a small 4-pass α -amplifier and a second 4-pass β -amplifier, and then transported to a vacuum grating compressor. The 600-ps, 1-J pulse is compressed to ~50 fs and propagated to the interaction region shown in Figure 2.

Inside the interaction chamber, the electron pulse is focused by a magnetic lens to a 50- μ m spot. The laser pulse is delivered and focused to the same interaction point from the opposite direction to collide with the electron bunch at an ~180° angle.

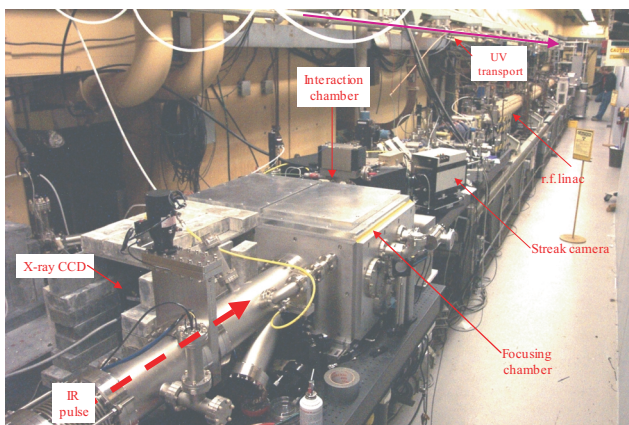


Figure 1. IR photons scatter off electron bunch in interaction chamber located on the linac in the basement of Bldg. 194.

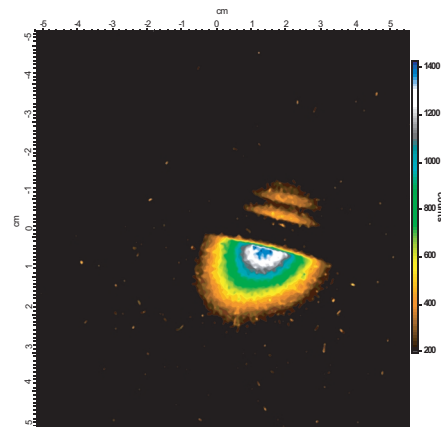


Figure 3. X-ray image from Thomson CCD camera. Top of beam is occluded by x-ray photodiode.

In the scattering chamber, the laser photon energy, E_L , is upshifted by an amount proportional to the square of the relativistic energy of the electrons. In our current experimental arrangement, the electron energy is 54 MeV, the energy of 800-nm photons (E_L) is 1.55 eV, and the energy of x-ray photons (E_x) is calculated to be 70 keV. Initial experiments were performed with the laser pulse and electrons interacting head-on. We are also designing experiments for 90° scattering between the electrons and photons, producing sub-picosecond x-rays.

Several diagnostic tools were developed to monitor the Thomson x-rays. Figure 3 shows an image of the Thomson x-ray beam monitored by an x-ray charge-coupled device (ccd). The estimated x-ray flux for this shot was 10^5 photons at an average energy of 70 keV, the highest brightness x-ray pulse at this energy ever produced. The top portion of the beam was occluded by one of the x-ray photodiode packages. Two other groups, one at LBL and the other in Japan, have produced comparable x-ray fluxes at lower energies, 30 keV and 14 keV, respectively. With straightforward improvements to the laser focal fluence and focused electron spot, we expect an ~1000-fold improvement in x-ray flux in the next few months.

—J. Crane, R. Cross, S. Betts, C. Barty, D. Gibson, G. Anderson, S. Anderson, W. Brown, D. Fittinghoff, F. Hartemann, J. Jacobs, L. James, J. Kuba, W. Patterson, C. Robbins, P. Springer, A. Tremaine, and V. Tsai